# Simulation for B-meson Tagging via Non-Prompt $D^0$'s with MVTX

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$$B \rightarrow \overline{D}^0 + X$$
$$B^+ \rightarrow \overline{D}^0 \pi^+$$

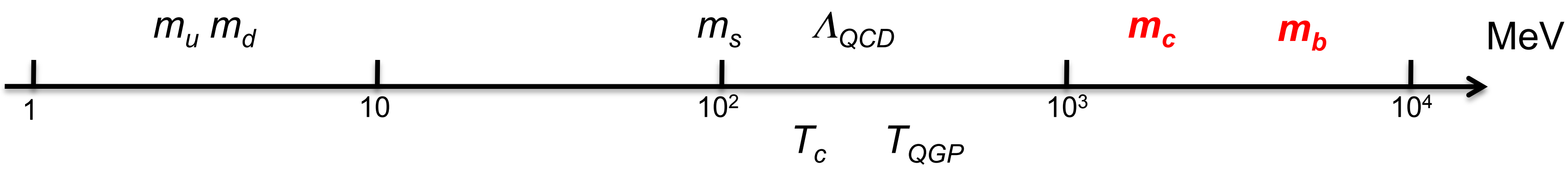
Physics introduction

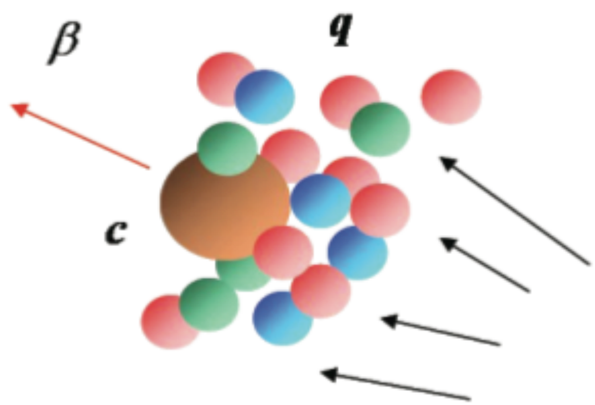
Simulation approach: Full GEANT simulation + fast MC

- Full GEANT simulation to provide input on efficiency, DCA distributions
- Fast MC to estimate reconstructed signal and background rates
- Projections for physics observables

*Simulation note to be released soon*

# Uniqueness of Heavy Quarks in QCD



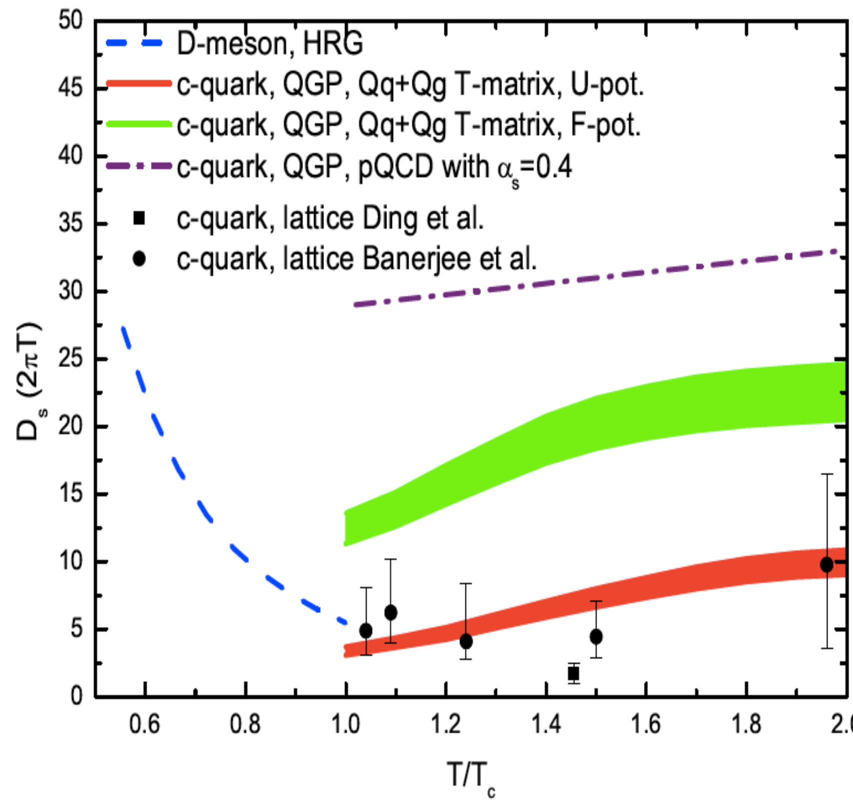

When $M_{HQ} >> T$, $M_{HQ} >> gT$

"Brownian" motion
→ Langevin simu.

$$\frac{dp^i}{dt} = -\eta_D p^i + \xi^i(t).$$

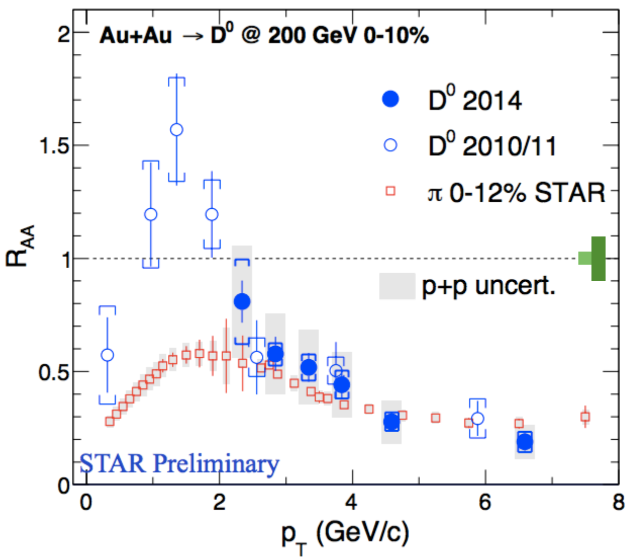
drag → Diffusion coefficient $D_{HQ}$

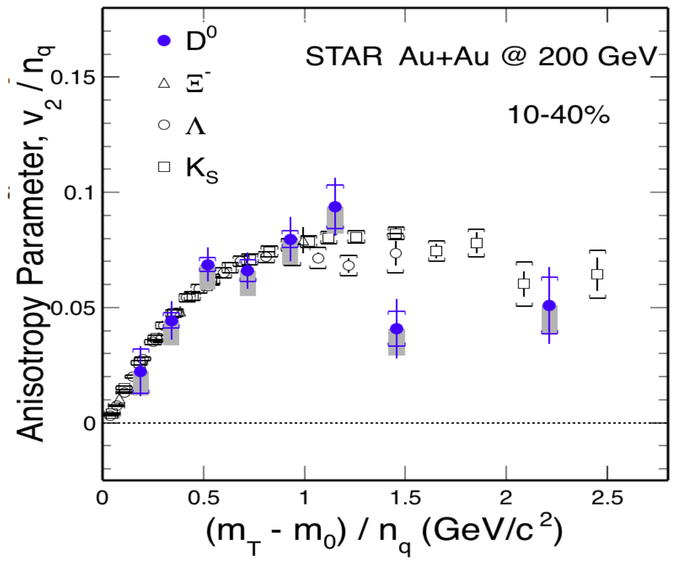
fluctuations → Diffusion coefficient $D_{HQ}$

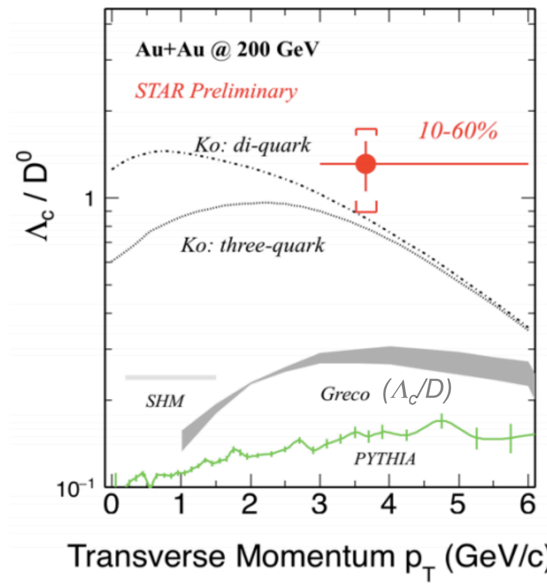



*QCD white paper - arXiv: 1502.02730*

# Charm Measurements




| | |
|---|---|
| $R_{AA}(D) \sim R_{AA}(h)$ ($p_T$>2 GeV/c) | - charm quarks lose significant energy |
| $v_2(D) \sim v_2(h)$ vs. $m_T$ | - charm quarks flow like light quarks |
| $\Lambda_c/D^0$ and $D_s/D^0$ enhancement | - coalescence hadronization |

Charm quarks very strongly coupled with QGP

***Evidence of charm quark flowing and possibly thermalized in the QGP***

# Go Heavier - Open Bottom Production

**Open bottom** production over a wide range of momentum

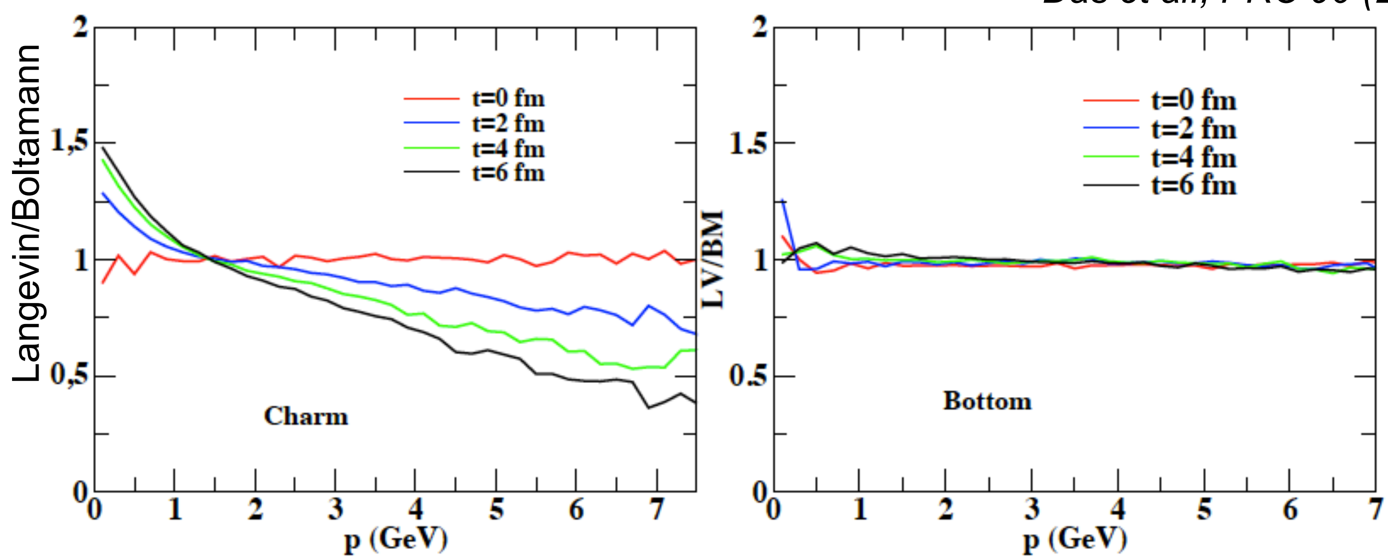
Mass/Flavor dependence of parton energy loss

Cleanest probe to quantify medium transport properties – e.g. $\boldsymbol{D_{HQ}}$

Total bottom yield for precision interpretation of Upsilon suppression

***- low $p_T$ coverage is critical***

*Das et al., PRC 90 (2014) 044901*




*Is charm heavy enough? Sizable correction to the Langevin approach for charm*

*- may limit the precision in determining* $\boldsymbol{D_{HQ}}$

# Physics Channels

| Hadron | Abundance | cτ (μm) |
|---|---|---|
| $D^0$ | 61% | 123 |
| $D^+$ | 24% | 312 |
| $D_s$ | 8% | 150 |
| $\Lambda_c$ | 6% | 60 |
| $B^+$ | 40% | 491 |
| $B^0$ | 40% | 455 |
| $B_s$ | 10% | 453 |
| $\Lambda_b$ | 10% | 435 |

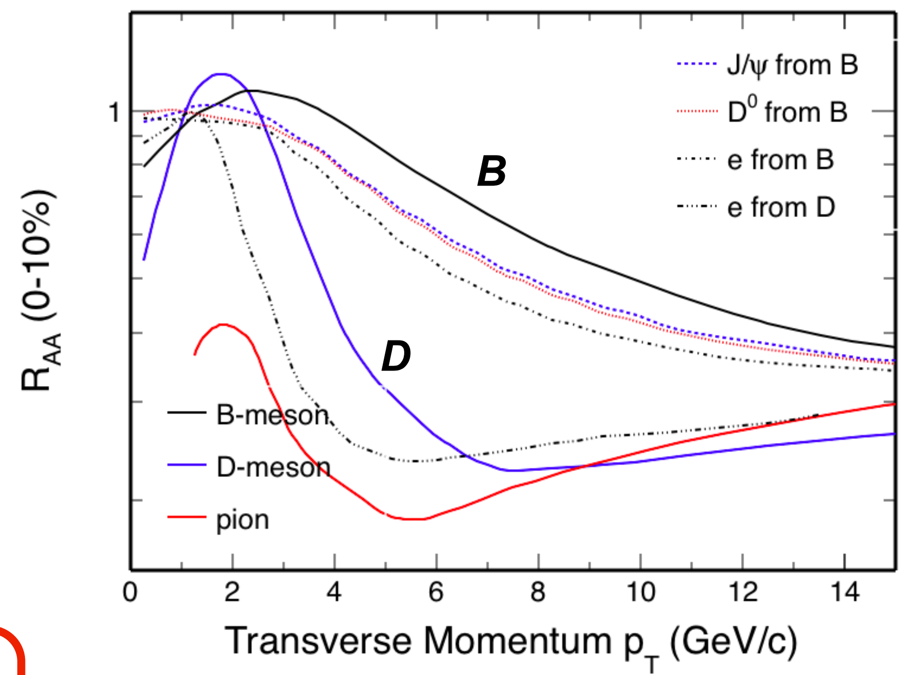
b-tagged jet $p_T$>15 GeV

$B \rightarrow \overline{D}^0 + X$ 60%

$B^+ \rightarrow \overline{D}^0 \pi^+$ 0.5%

$p_T$<15 GeV

exploring $B \rightarrow J/\psi + X$




*Theory curves on B/D-mesons from TAMU/DUKE/CUJET*

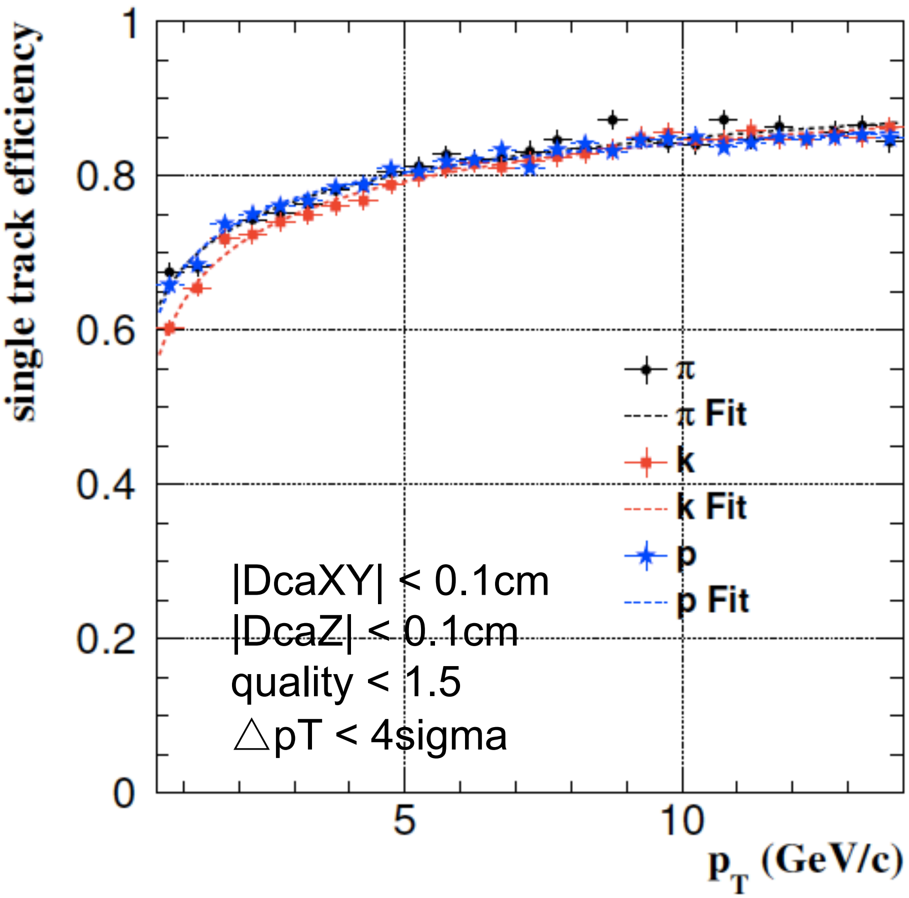
# Simulation Approach

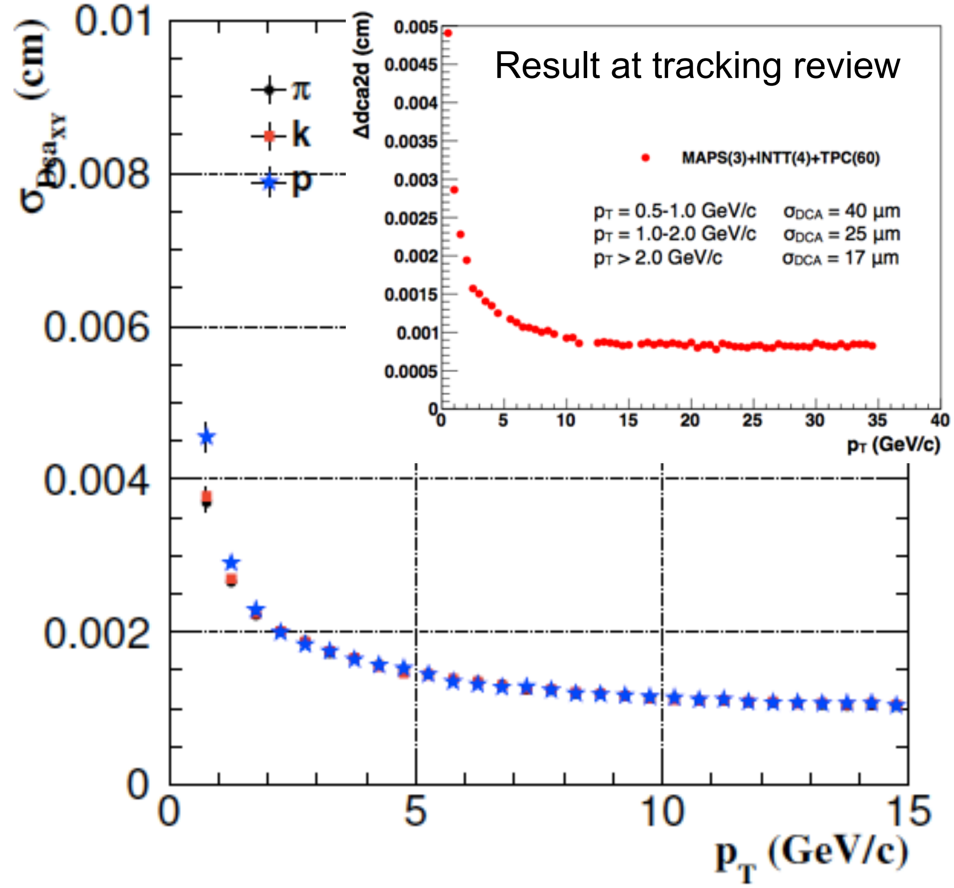
## Full GEANT simulation + fast MC

- Full GEANT simulation to provide input on efficiency, DCA distributions
- Fast MC to estimate reconstructed signal and background rates
- Projections for physics observables

# Full GEANT Simulation

Central 0-10% Hijing events + 30 embedded pi/K/p tracks each
Hough transformation tracking software (not the new tracking)



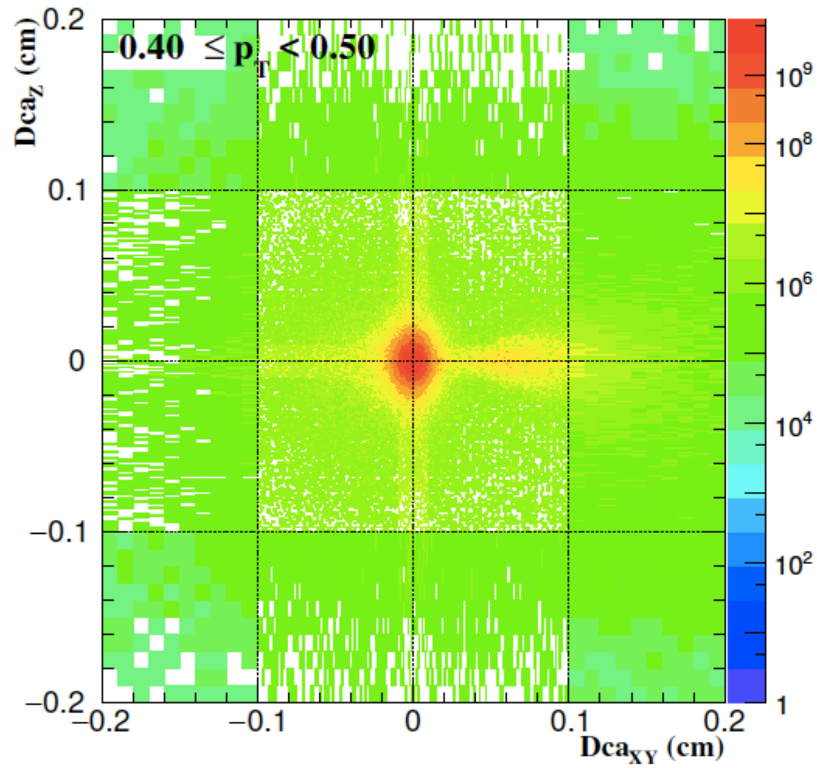

Reasonable agreement with performance shown at tracking review,
despite some detail difference to be sorted out.

# Fast Simu Procedure

Fast simulation package:
1) Sample event vtx distributions
2) Throw signal (D0, B) or background (pi,K,p from Hijing) tracks, decay if needed
3) Smear the track origin with (DCAxy, DCAz) 2D distributions
4) Smear the momentum according to the momentum resolution
5) Full reconstructed helices -> reconstruct secondary vertex
6) Calculate the signal efficiency or background accept-rate

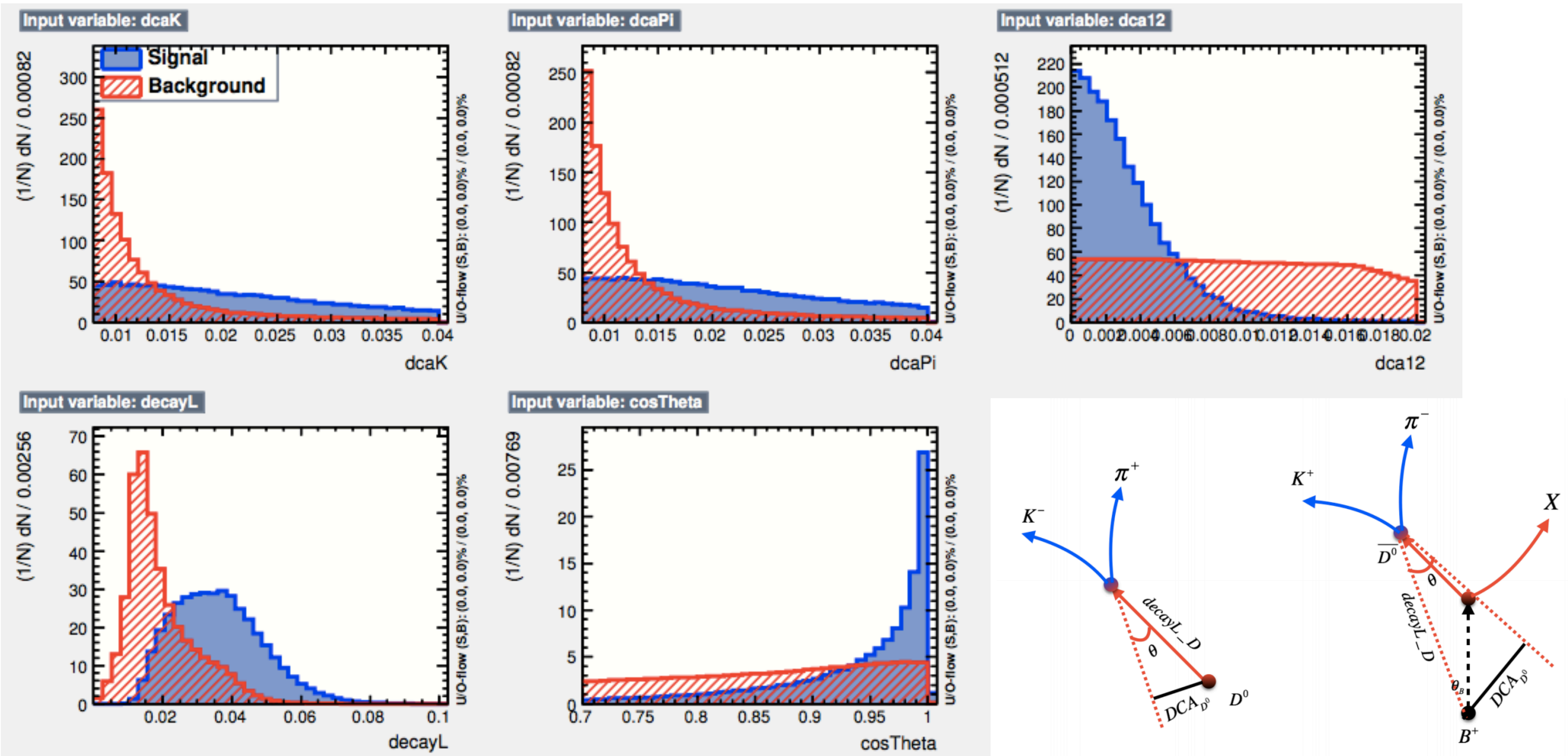
Based on the package originally developed for STAR HFT efficiency calculation (data-driven).

Key input, (DCAxy, DCAz) 2D distributions



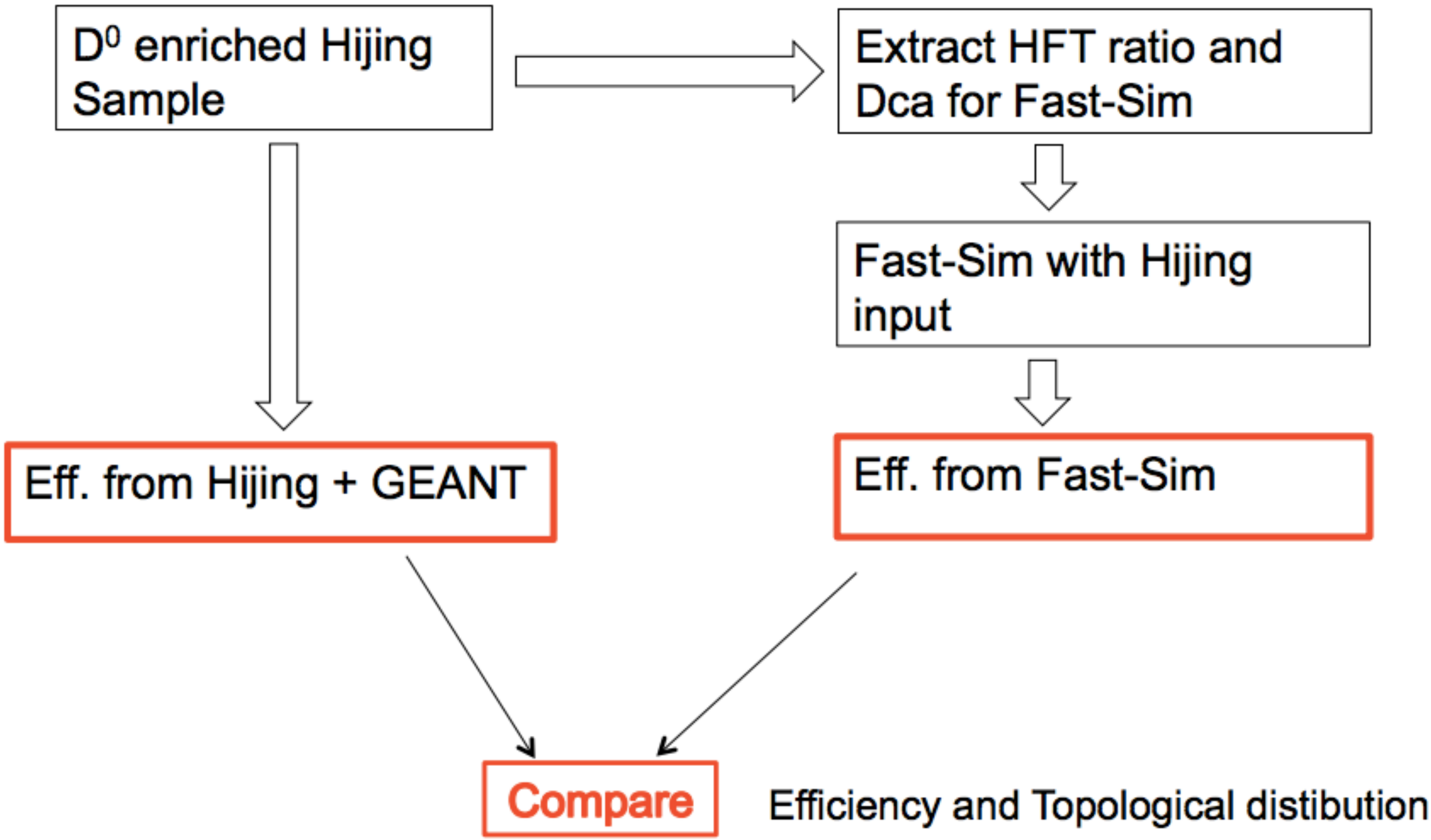
# Topological Recon. of Prompt and Non-Prompt $D^0$

Topological variable distributions for non-prompt $D^0$ at 2-3 GeV/c, 0-10%



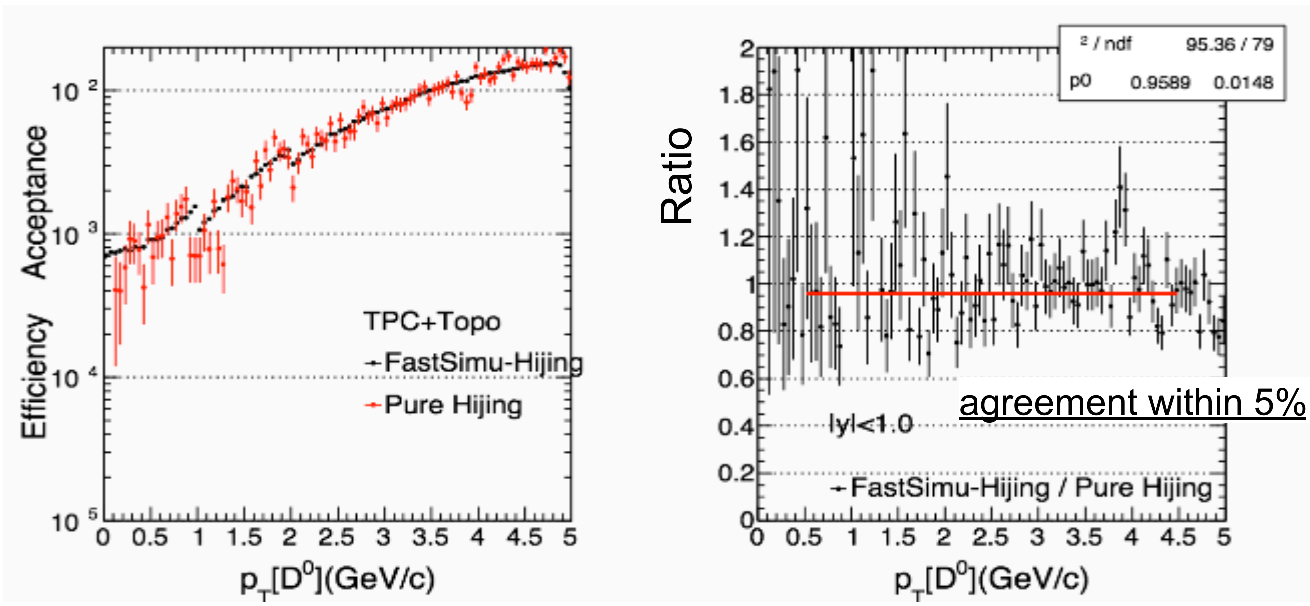

Topological cuts optimized by TMVA package ("cut method" used only here)

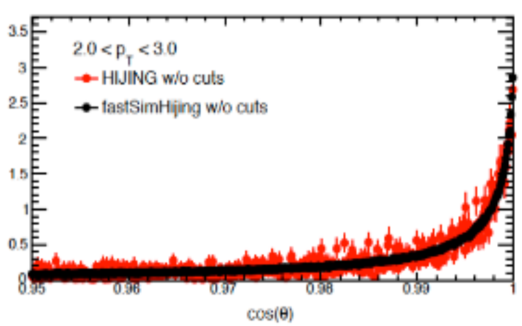
# Validation of Signal Eff. with Full GEANT Simulation

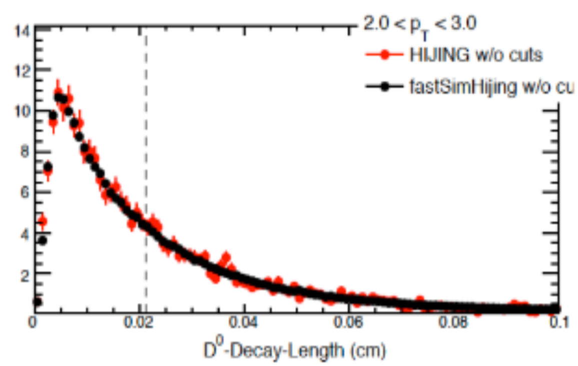


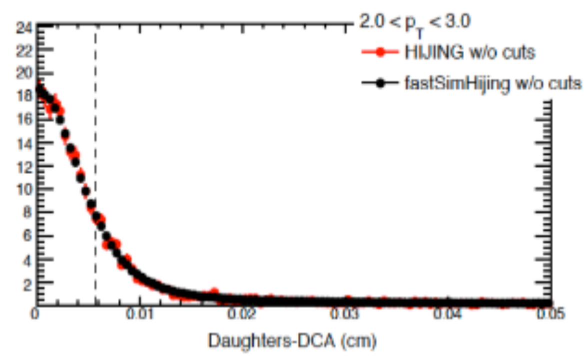
# Validation of Signal Eff. with Full GEANT Simulation

- Hijing+$D^0$ sample through GEANT + reconstruction
- Fast simu – inputs taken from Hijing single track performance
- Then compare the efficiencies between fast simu vs. that from Hijing+GEANT directly

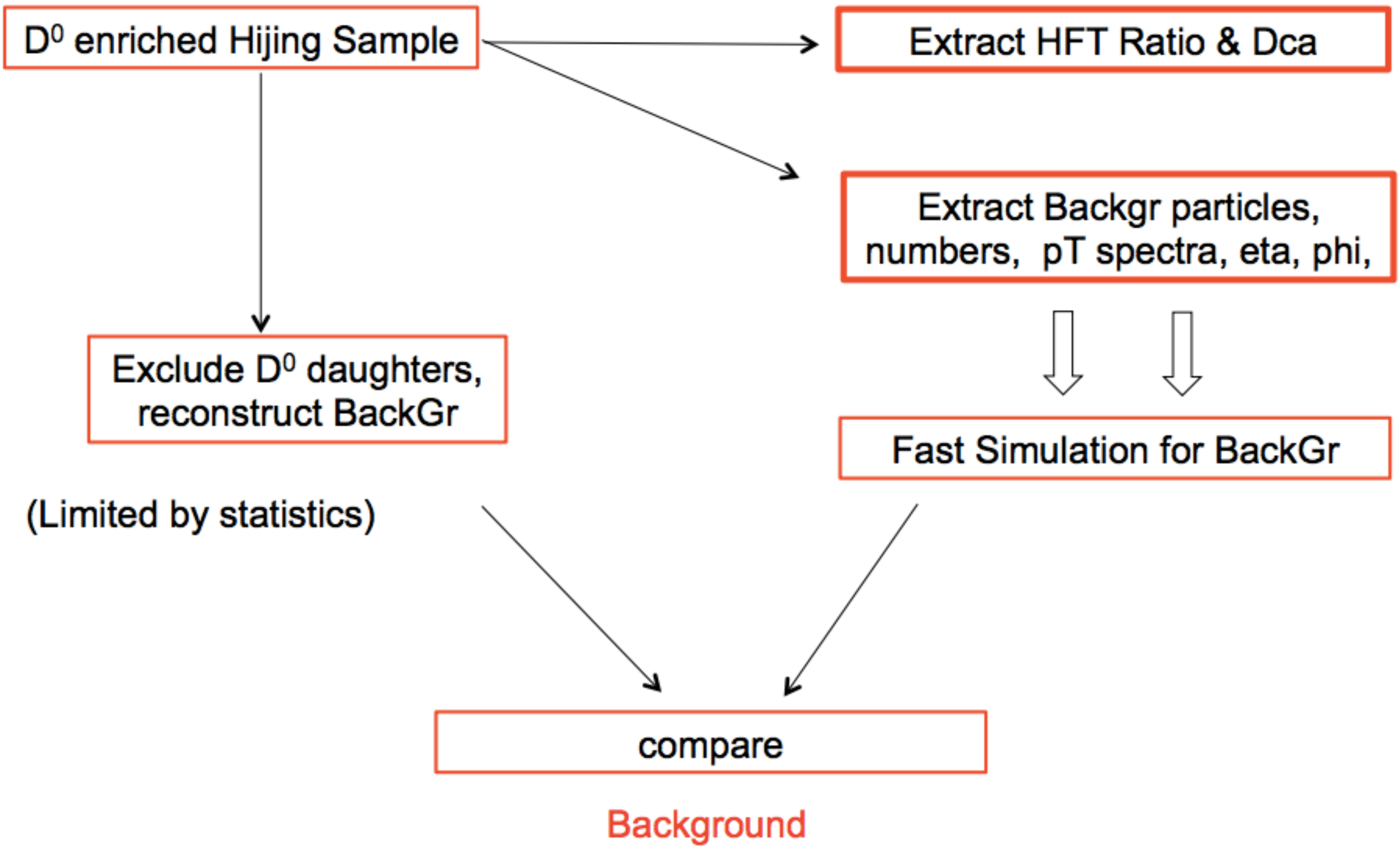


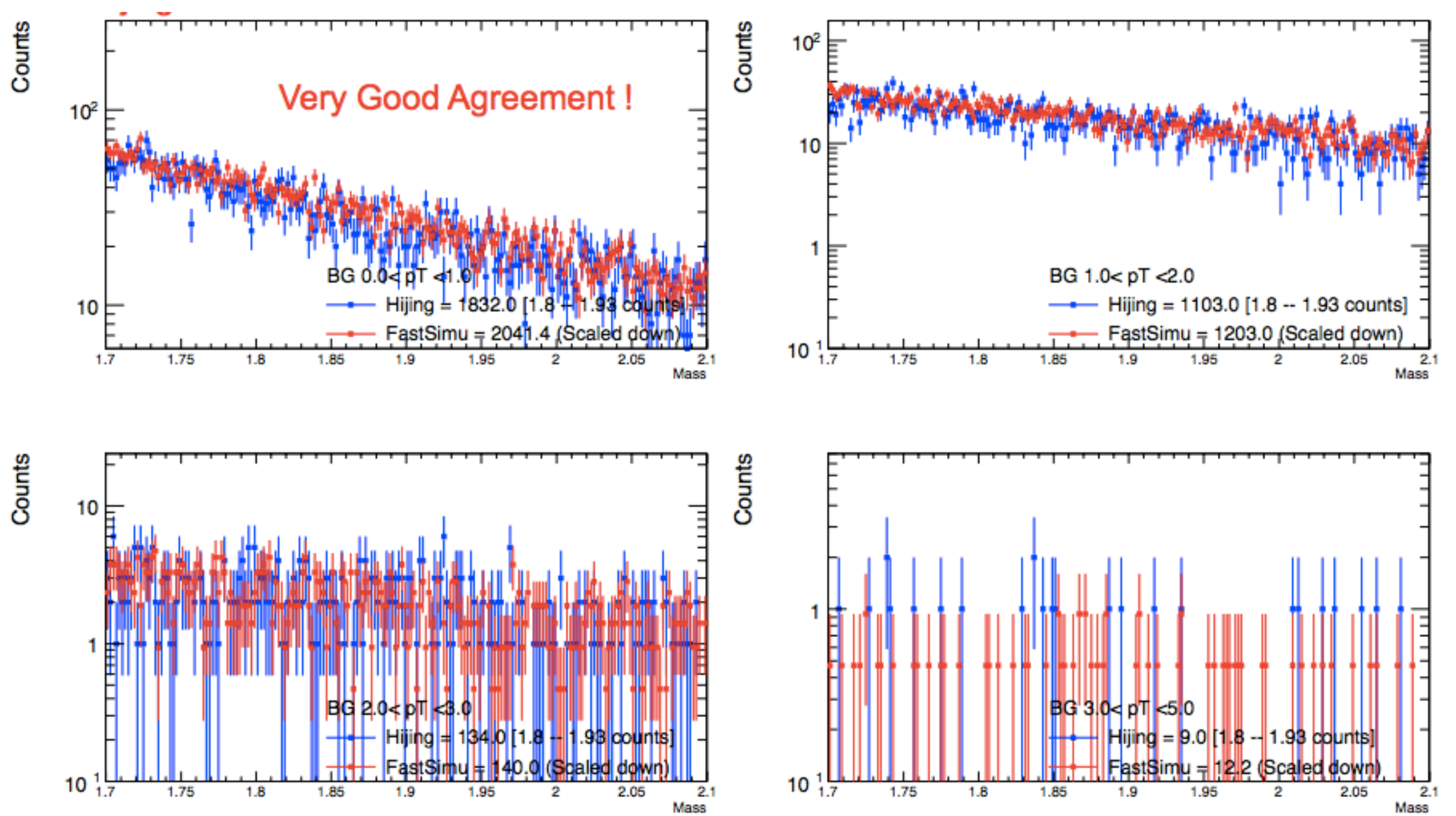



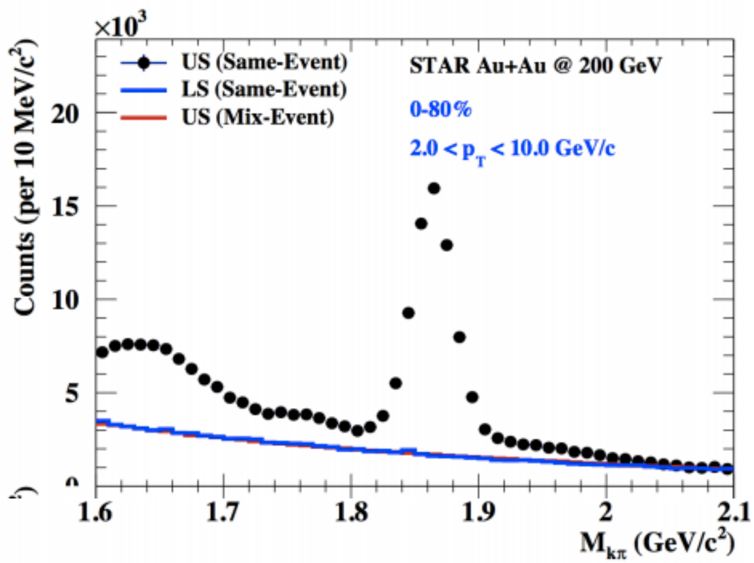
# Validation of Bkgd with Full GEANT Simulation



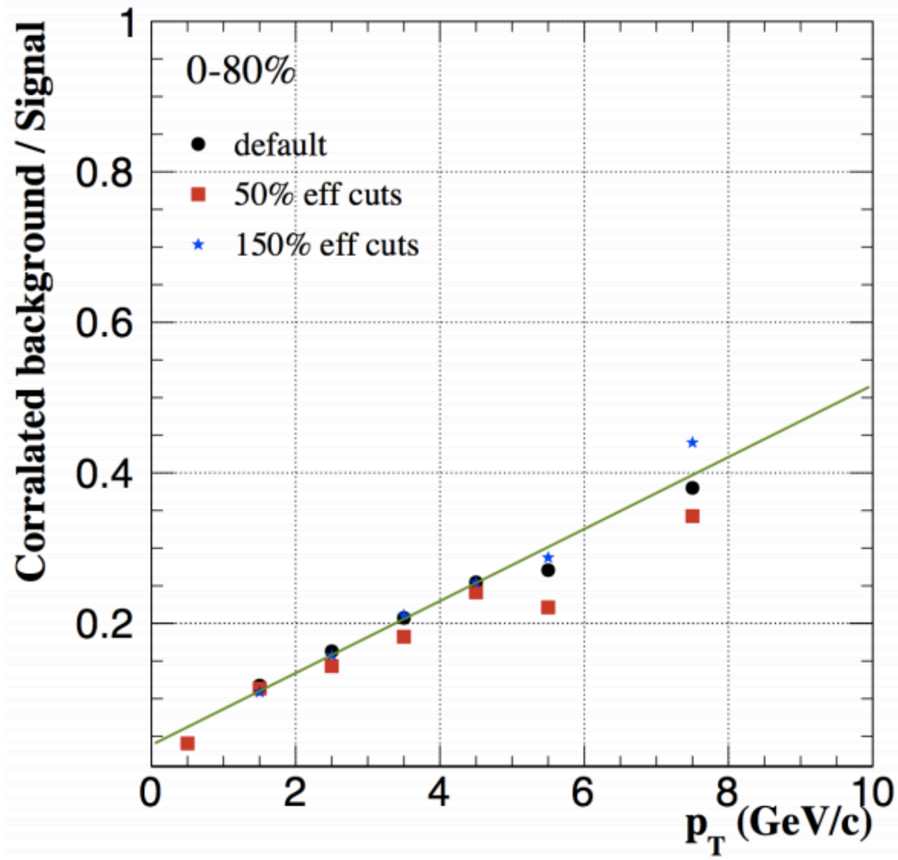
# Validation of Bkgd with Full GEANT Simulation



# Correlated Background

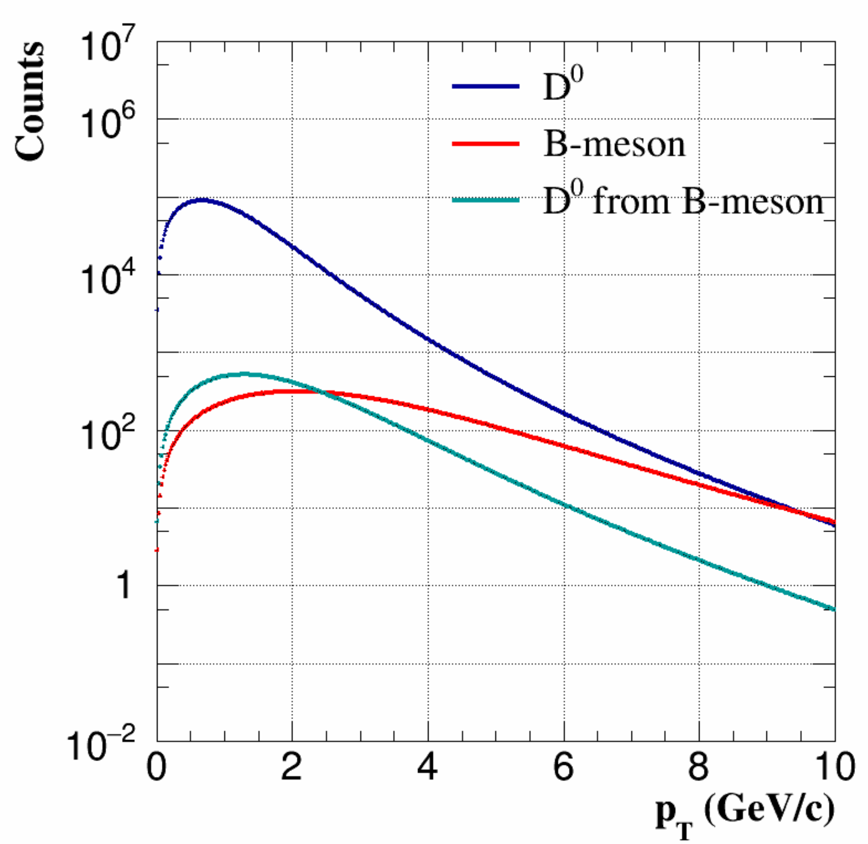



Based on STAR HFT data



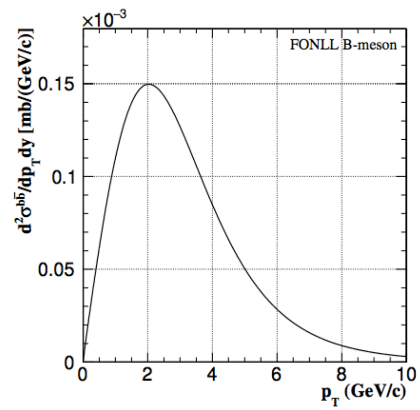

- Correlated background sources:
  jet fragmentation, doubly mis-PID etc.
- First order estimation based on the STAR HFT data by taking the ratio of correlated background to signal counts

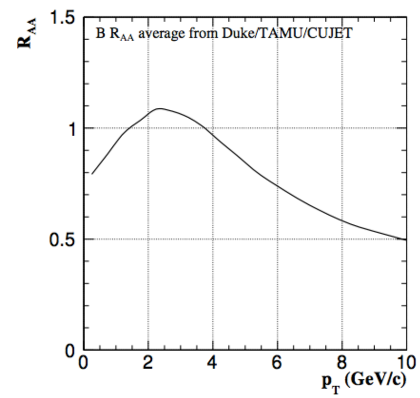
# Bottom Input based on pQCD FONLL




B-meson decay using PYTHIA
Scaled to B.R. according to PDG

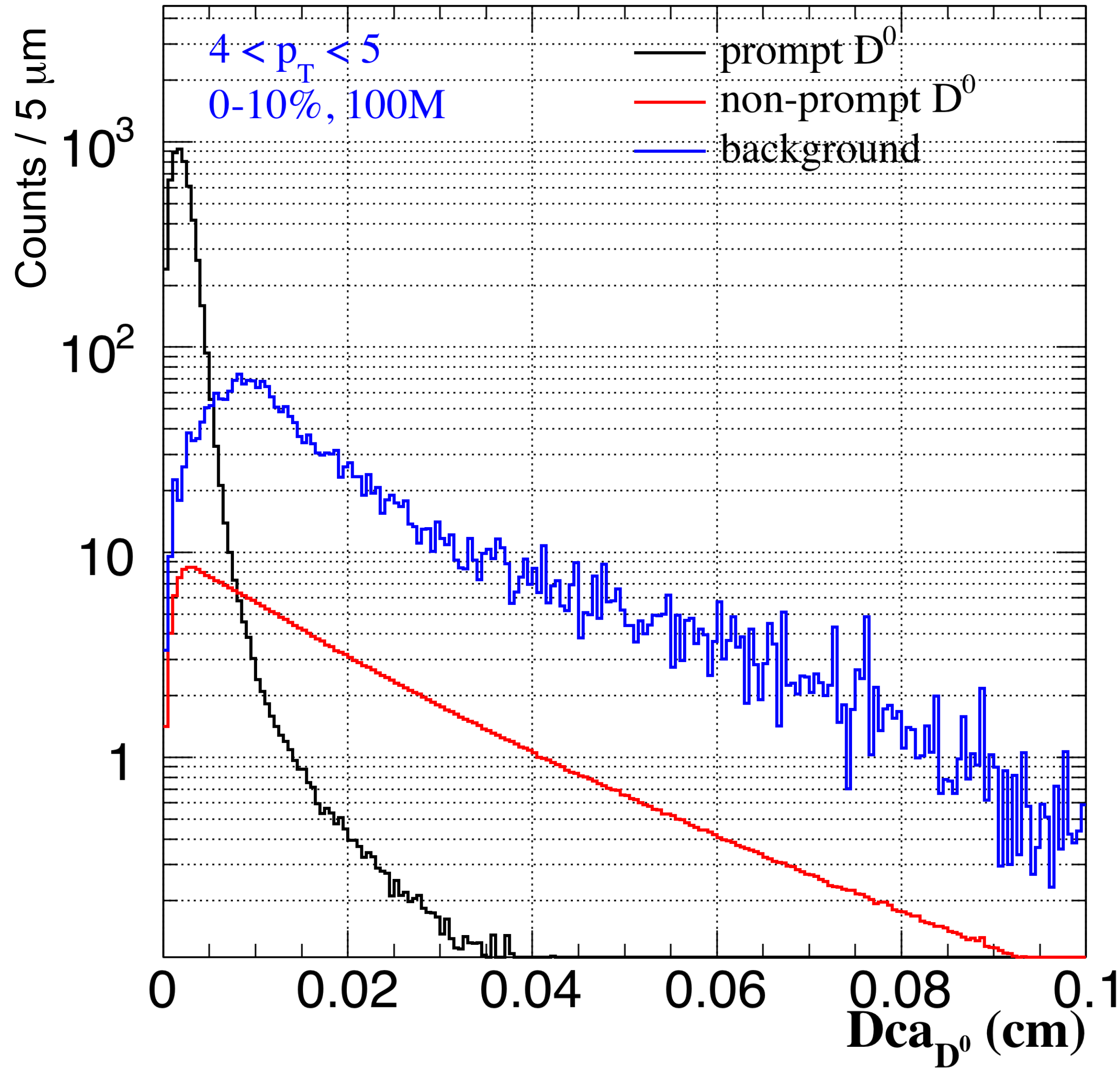
Default:
FONLL*$N_{bin}$ for AuAu
In physics performance plot $R_{AA}/R_{CP}$,
$R_{AA}$ is applied in addition for signal

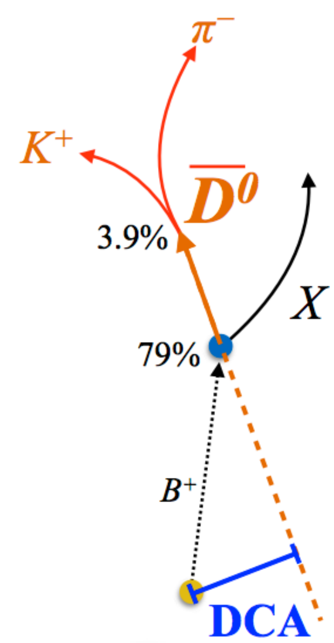


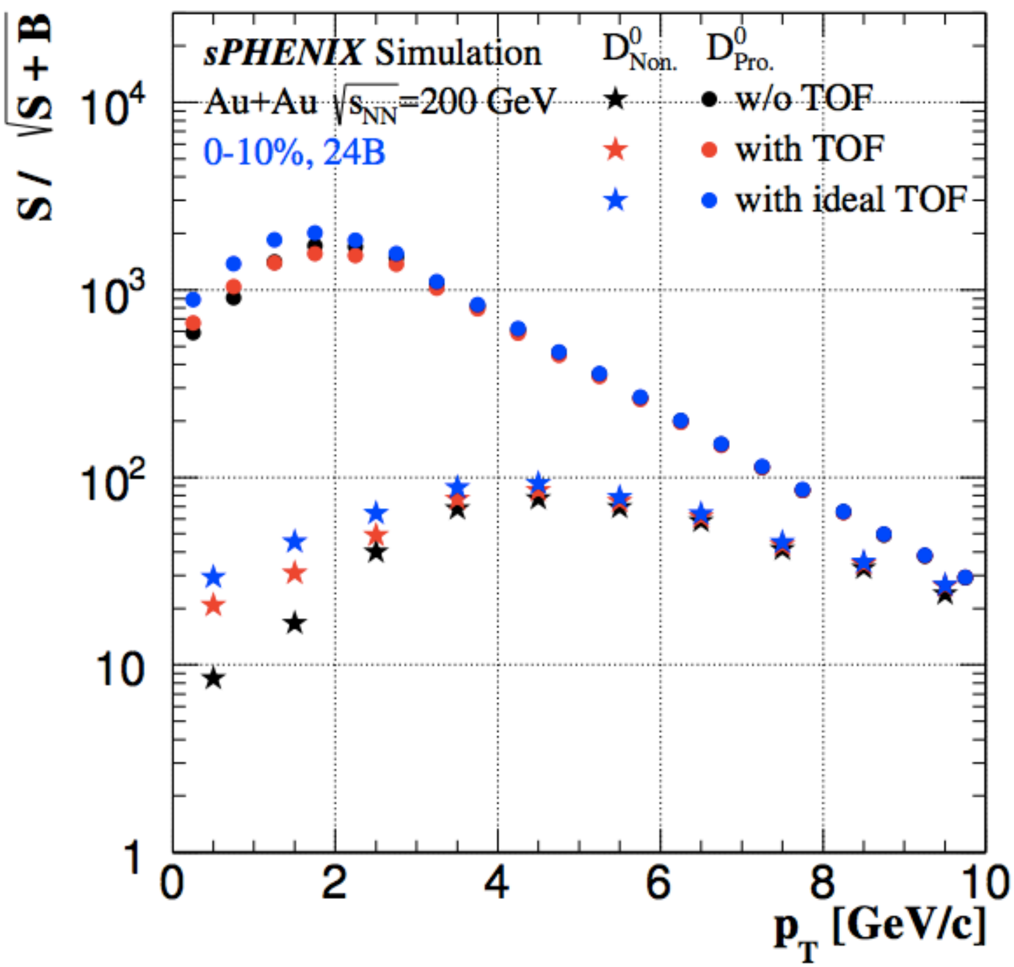

| Particle | $c\tau(\mu m)$ | Mass$(GeV/c^2)$ | $q(c,b)\rightarrow X(FR)$ | $X\rightarrow D^0(\overline{D^0})\ (BR)$ |
|---|---|---|---|---|
| $D^0$ | 123 | 1.865 | 0.565 | - |
| $B^0$ | 459 | 5.279 | 0.40 | 0.081(0.474) |
| $B^+$ | 491 | 5.279 | 0.40 | 0.086(0.790) |

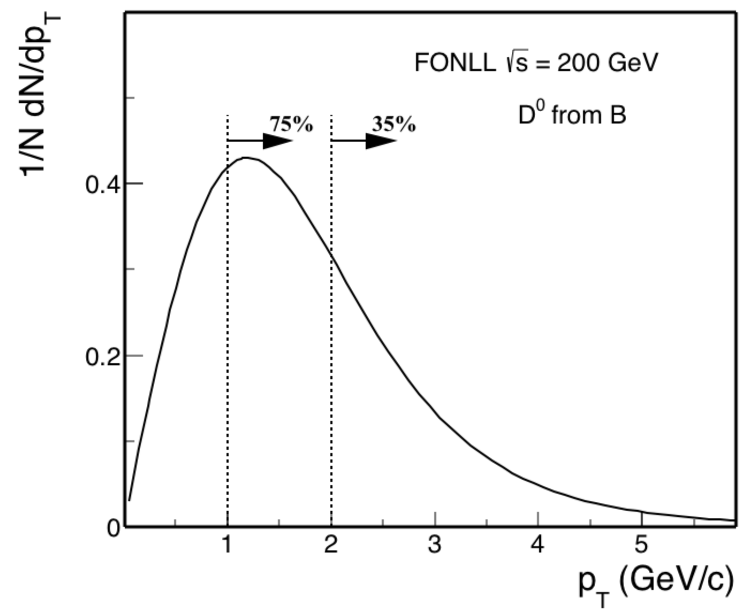
# Reconstructed $D^0$ DCA Distributions



# Estimation on Signal Significance

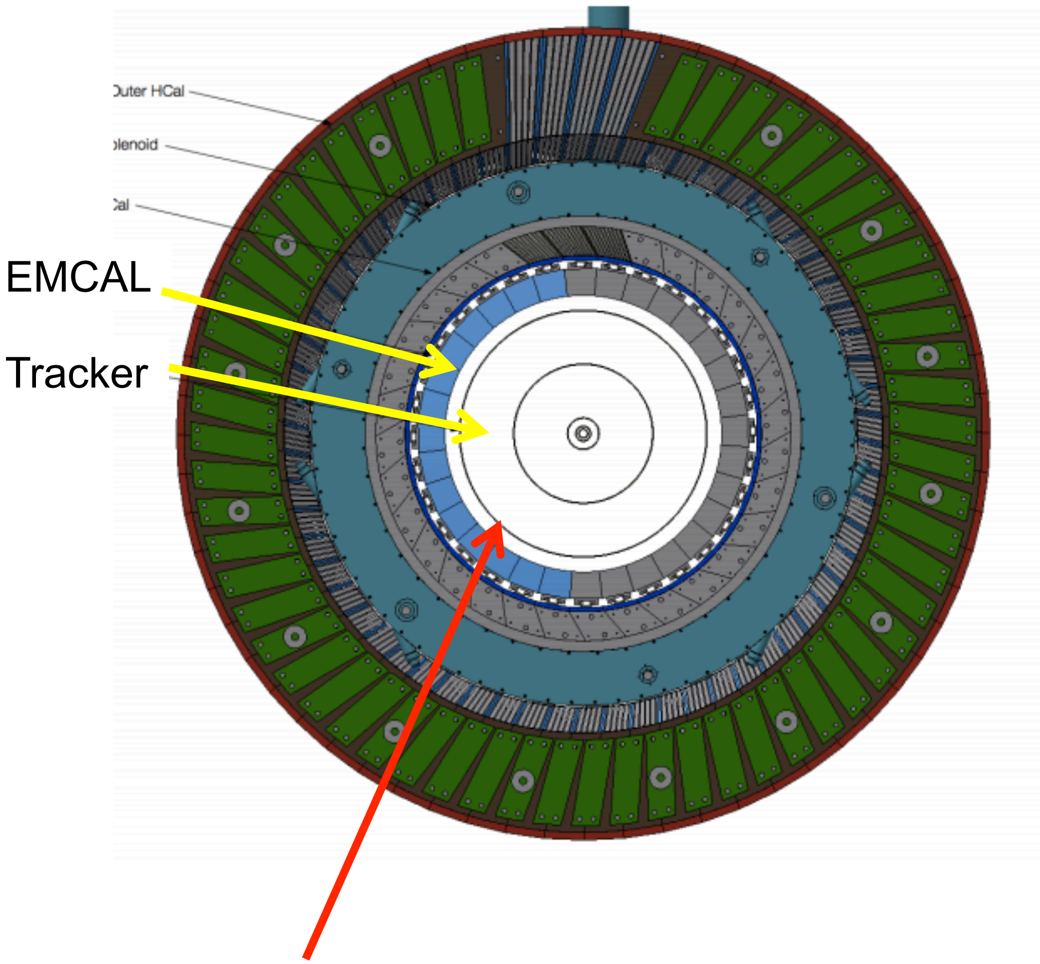



Good performance for measuring non-prompt $D^0$ at low $p_T$ with sPHENIX

PID detector (TOF) can help further improve particularly the low $p_T$ precision
- constrain the total bbbar X-sec

# Particle Identification with TOF




10cm gap between TPC and EMCAL - TOF

TOF PID requirement:

$$M = p\sqrt{\left(\frac{ct}{L}\right)^2 - 1}$$

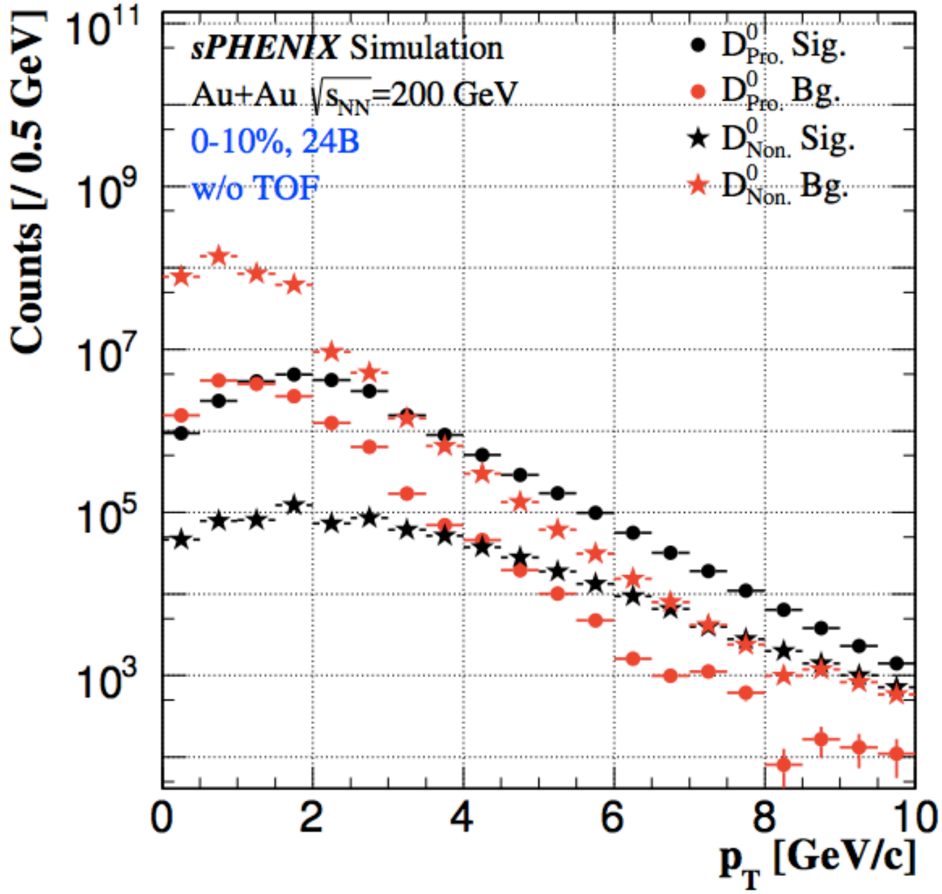
$$\frac{\Delta M}{M} = \frac{\Delta p}{p} \oplus \gamma^2 \left[\frac{\Delta L}{L} \oplus \frac{\Delta t}{t}\right] \sim \gamma^2 \frac{\Delta t}{t}$$

STAR TOF:
Radius ~ 2.15 m, $\sigma_t$ ~ 65 ps

sPHENIX TOF
(to have the same PID capability)
Radius ~ 0.85 m, **$\sigma_t$ ~ 25 ps**

Simplified PID assumed:
Clean pi/K PID at pT<1.6 GeV
No pi/K PID at pT>1.6 GeV

# S/B Ratios

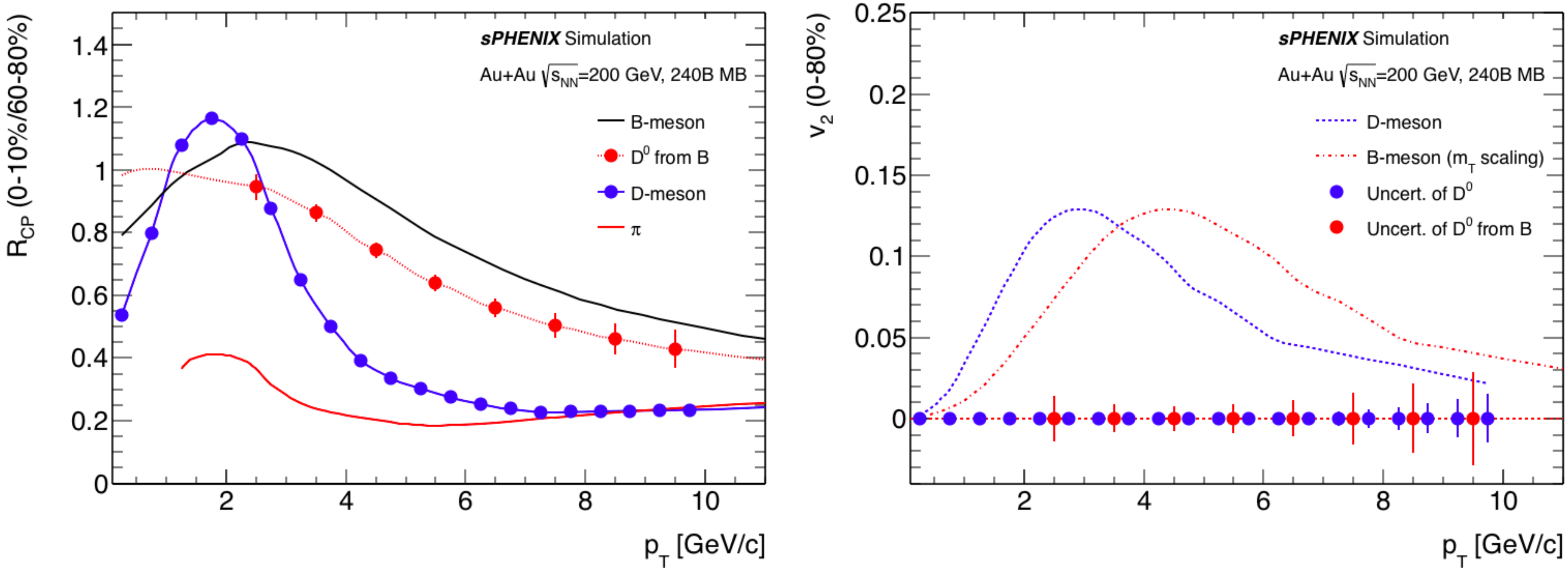



With topological cuts:

- For prompt $D^0$, S/B ratio is ~1, so no big worry about systematic uncertainty control
- While S/B ratio is <1/100 for non-prompt $D^0$ at $p_T$ < 2 GeV/c, systematic uncertainty may play an important role at very low $p_T$.
  - PID detector can improve the S/B by a factor of 10 – a big help at very low $p_T$

# Physics Performance via Non-Prompt $D^0$

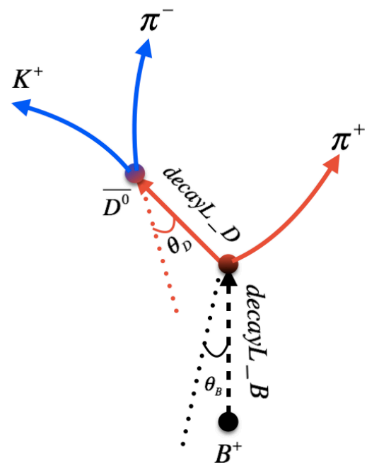
240B MB Au+Au collisions at 200 GeV

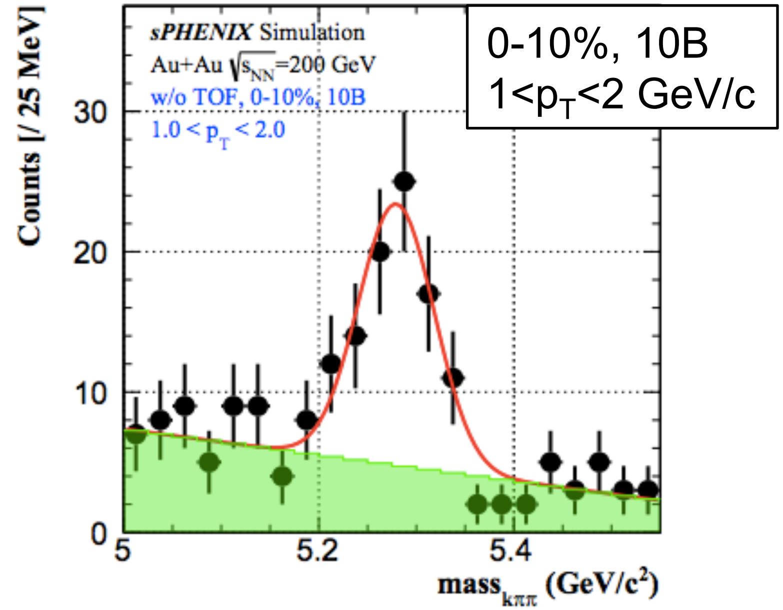



1) Nuclear modification factor $R_{CP}(R_{AA})$ up to ~10 GeV/c
 - to precisely study the mass hierarchy of parton energy loss

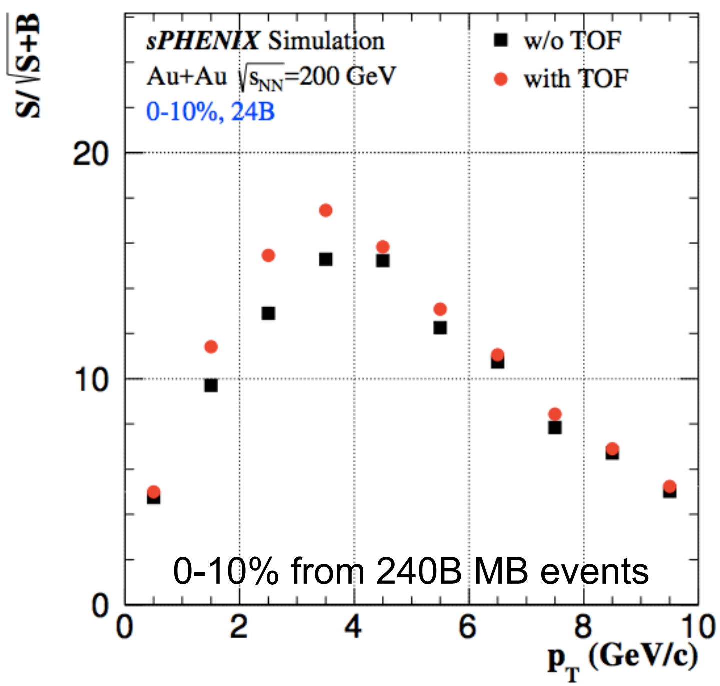
2) Elliptic flow ($v_2$) up to ~8 GeV
 - to precisely determine the bottom quark collectivity, therefore to constrain diffusion coefficient $\boldsymbol{D_{HQ}}$

# Full B-meson Reconstruction



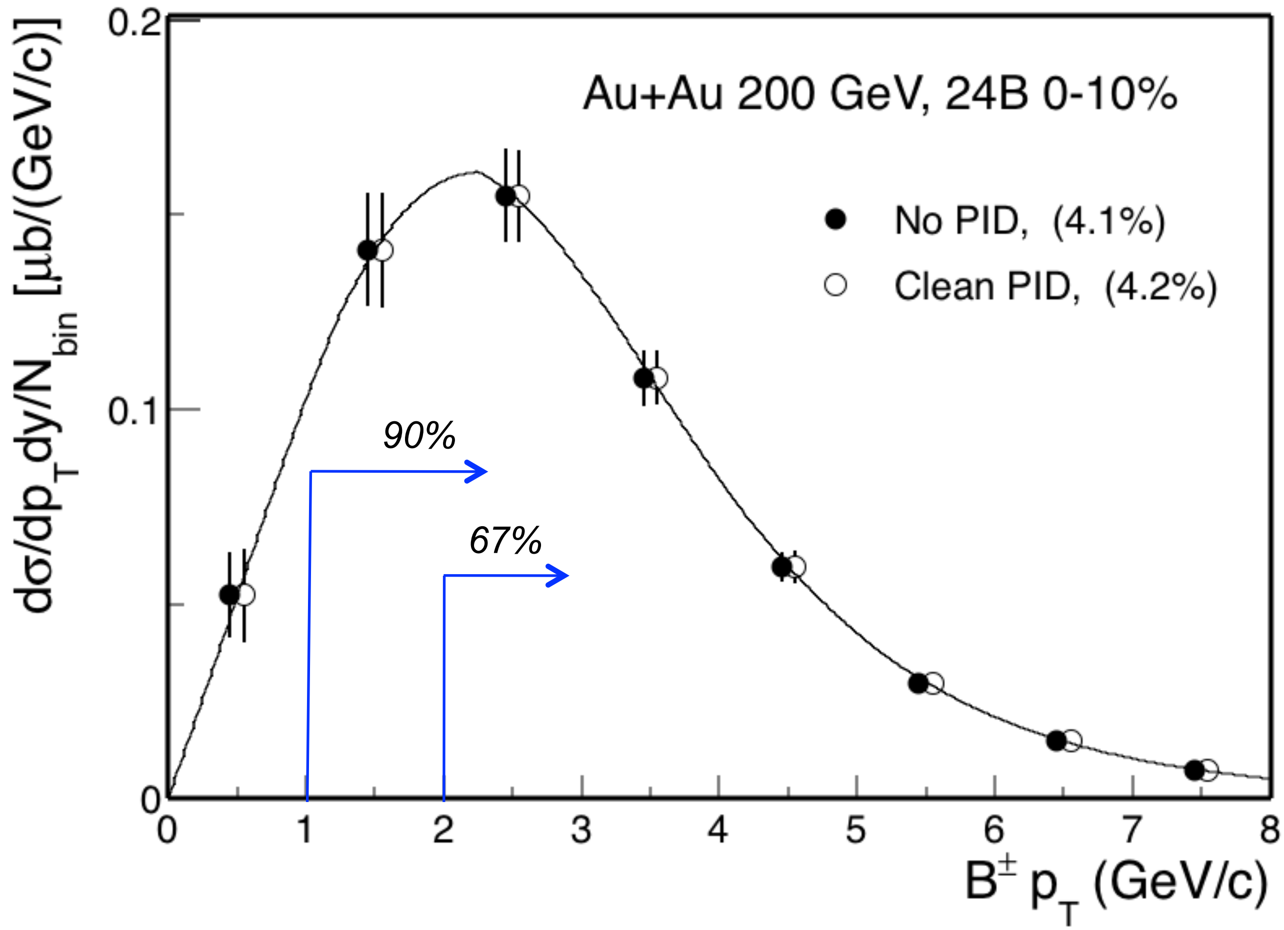

Estimated B+ signal/background in 10B 0-10%




Topological cuts optimized via TMVA BDT method

A reasonable measurement of B+ hadrons via exclusive decay channel in ~0-10 GeV/c
- complementary and different systematic control at low $p_T$

# Constrain Total Bottom X-sec




With exclusive B+ reconstruction, total dσ/dy uncertainty can be controlled to <5%!

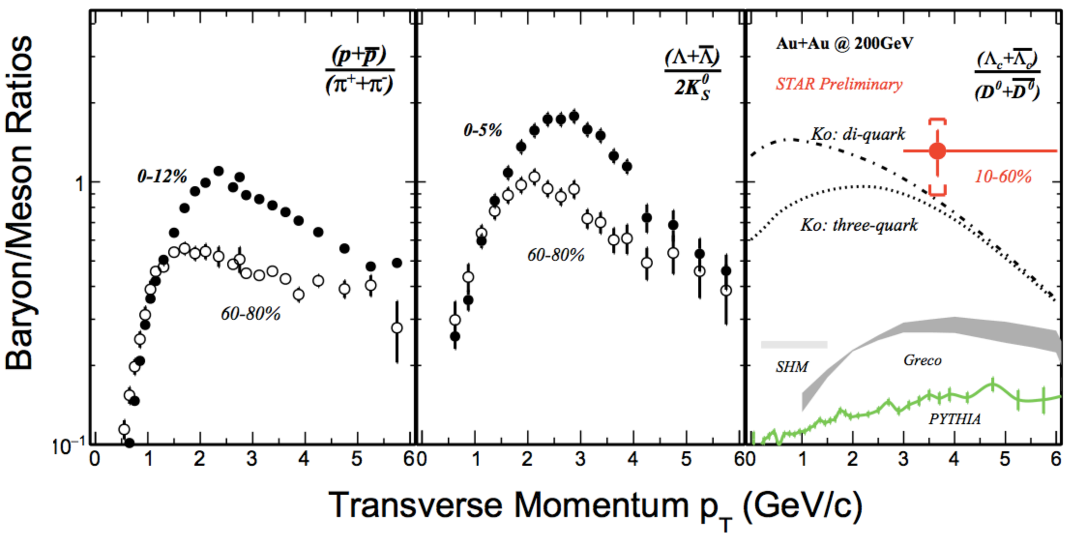
# Broad HF Physics Program: $\Lambda_c$ and HQ Correlations

**High statistics $\Lambda_c$ measurements**

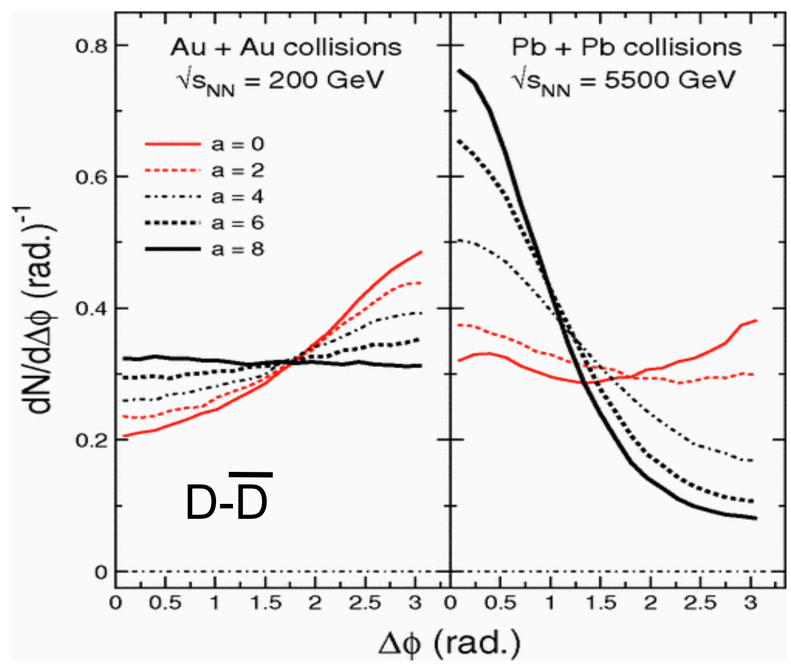
$\Lambda_c/D^0$ enhancement sensitive to
- charm quark hadronization, thermalization, domains in sQGP etc.

**Heavy quark correlations**

• More sensitivity to HQ-medium interaction, thus better determination of $\Delta E$ mechanisms and $D_{HQ}$
• LHC vs. RHIC – different initial pair correlation/medium dynamics




*Lee et al, PRL 100 (2008) 222301*
*Ghosh et al, PRD 90 (2014) 054018*
*STAR, QM17*




*Zhu et al, PRL 100 (2008) 152301*

# Summary

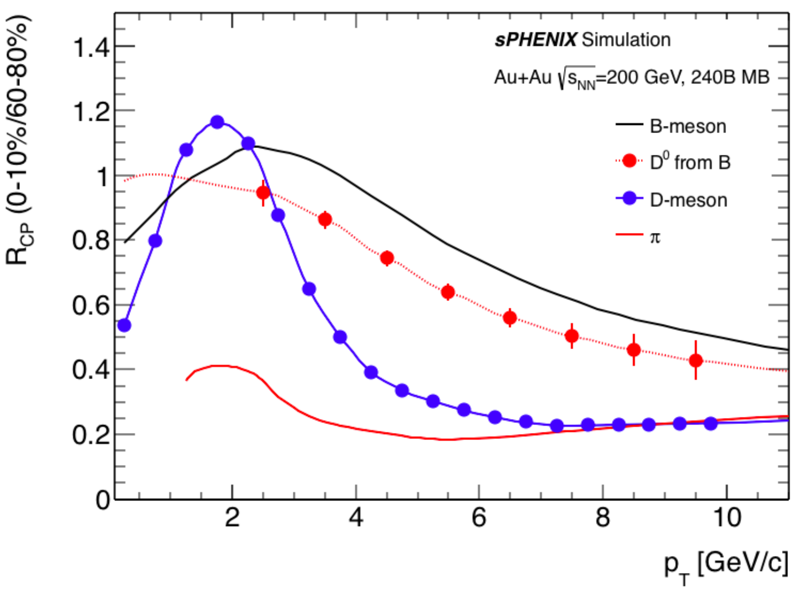
• Heavy flavor (phase-II) to complete RHIC science mission (2021-2025)

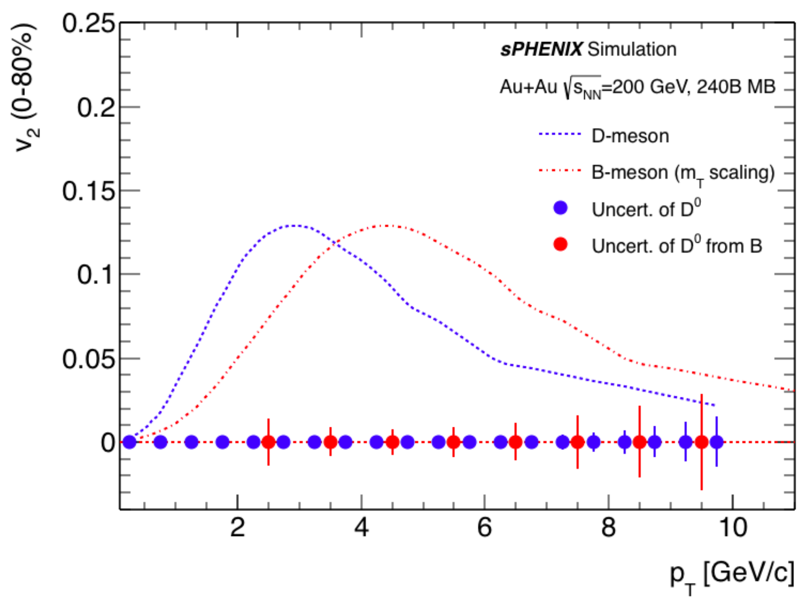
**Precision open bottom measurement over a broad momentum range**

- and charm chemistry / HQ correlation measurements

**- mass dependence of parton energy loss mechanisms**
**- temperature dependence of heavy quark diffusion coefficient**

• MVTX with other sPHENIX sub-detectors will be able to deliver B-meson measurements at ~0-10 GeV/c via
  • inclusive non-prompt $D^0$
  • exclusive $B^+ \rightarrow \bar{D}^0 + \pi^+$

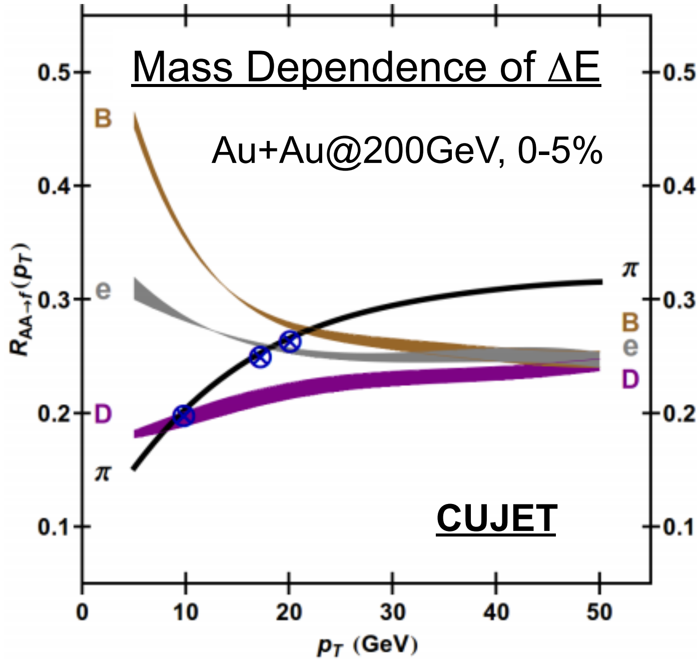


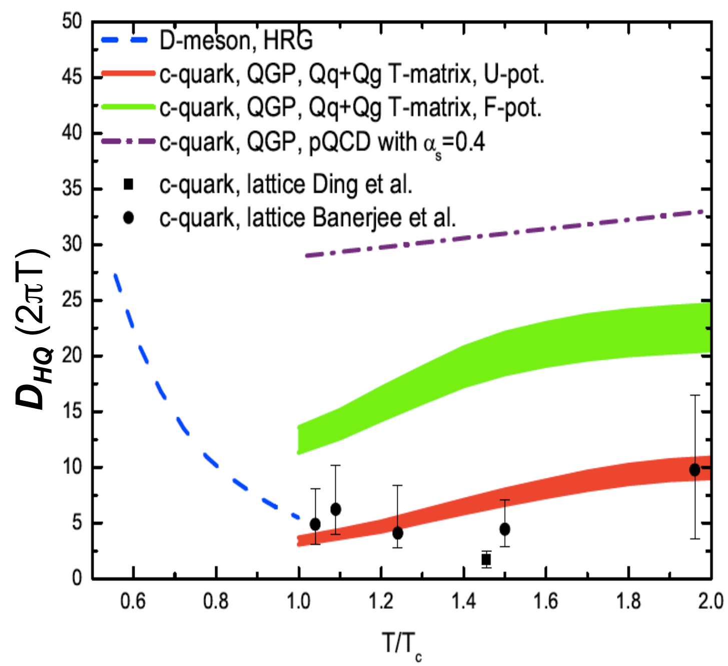
# Physics Goals of Heavy Flavor Measurements

- Mass dependence of parton energy loss
- Quantify the medium transport parameter

  – heavy quark diffusion coefficient, $\boldsymbol{D_{HQ}}$

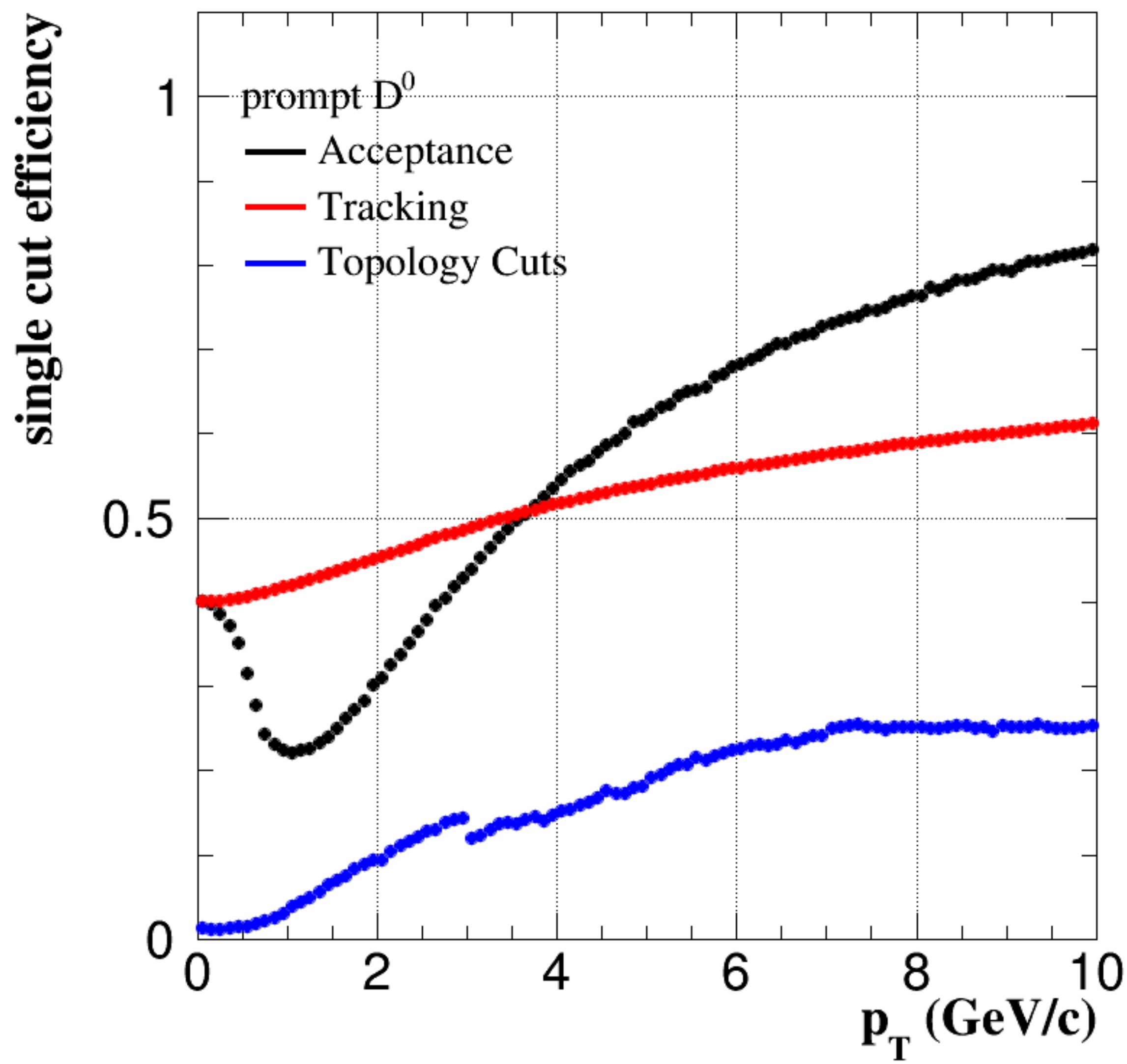



*PRL 108 (2012) 022301*




*QCD white paper - arXiv: 1502.02730*

# Reconstruction Efficiency



# $D^0$ Signal at 0-1 GeV/c from STAR HFT